



# **Air Force Science & Technology Issues & Opportunities Regarding High Performance Embedded Computing**

***23 September 2009***



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**Air Force Research Laboratory**  
**Information Directorate**

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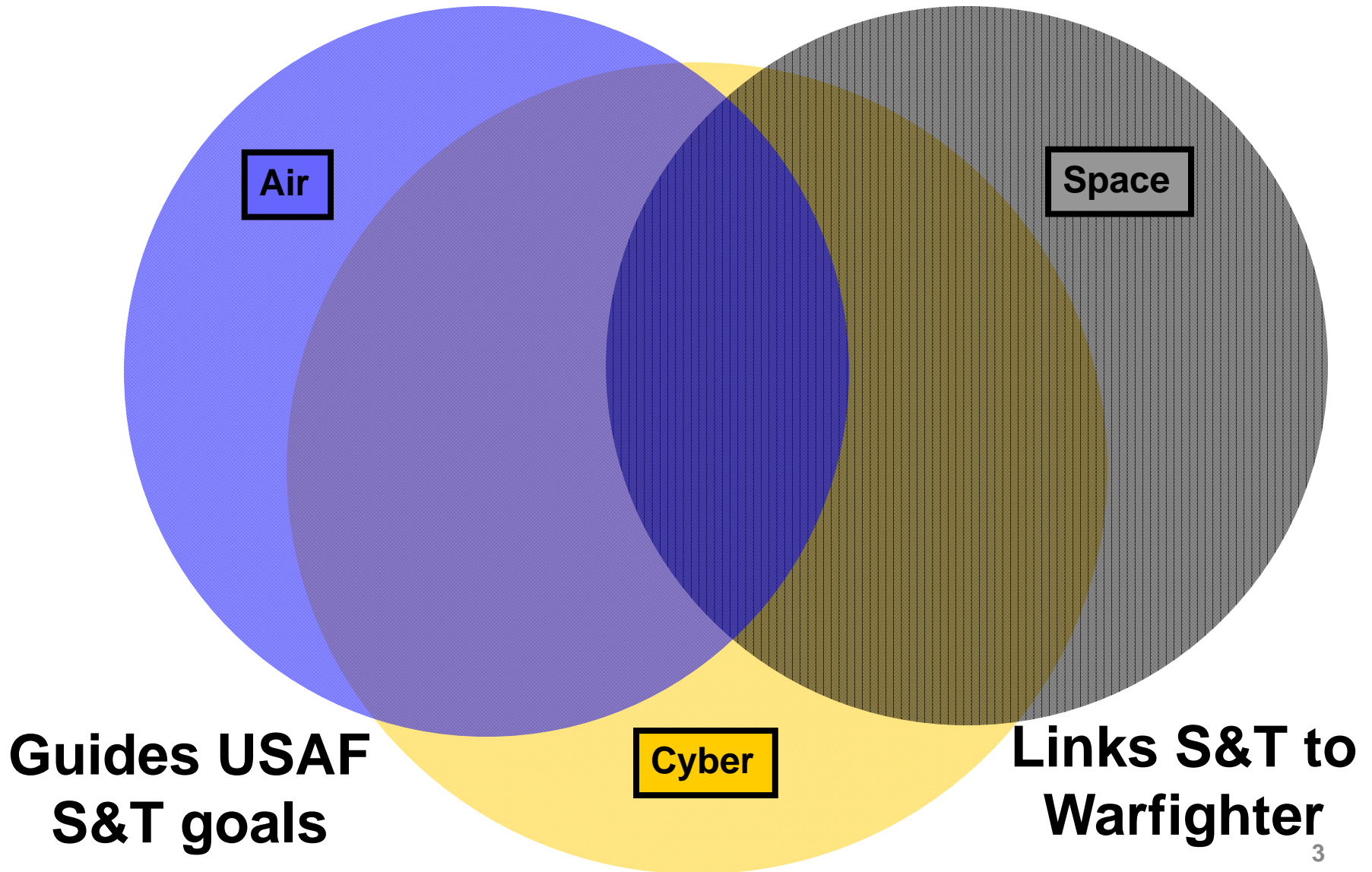
**The mission of the United States Air Force  
is to fly, fight and win...  
in  
Air, Space and Cyberspace.**







# USAF S&T Vision





# AFRL Mission

**Leading** the discovery, development, and integration of affordable warfighting technologies for our air, space and cyberspace force.

It's not just about the science...  
...it's about leadership in S&T



# Challenges by Domain



- **Air:** Persistent air dominance is at risk
  - Increasingly effective air defenses
  - Proliferation of 5<sup>th</sup> gen fighters, cheap cruise missiles, and UASs
  - Light-speed war possibilities are terrifying
- **Space:** Now a contested domain
  - Increasingly important
  - Increasingly vulnerable
- **Cyber:** Cyber warfare has begun
  - We don't control the battlespace
  - We rely on it more and more
  - We can't find the enemy





# Opportunities – Air: Across the Technology Spectrum



- **Endurance** – Efficient aerodynamics, efficient propulsion, lightweight structures
- **Alternative Fuels** – Fischer-Tropsch, biomass, carbon sequestration
- **Sensors** – 360 degree coverage, structural load-bearing antennas
- **Speed** – Hypersonics, thermal, flight controls, maneuverability, payloads
- **Thermal Management** – Produce less heat, tolerate more heat, dissipate more efficiently, convert more effectively
- **Modeling & Simulation** – Virtual prototyping, live-virtual-constructive environments
- **Manufacturing Technology** – Lean, diagnostics, just-in-time production
- **UASs** – Swarming, semi-autonomous then autonomous, learning, healing
- **Micro Air Vehicles** – Sensor miniaturization, flight agility, autonomy
- **Integrated Systems Health Management** – Self-reporting systems, autonomous reconfiguration to maintain mission capability
- **Responsive** to needs of sister services, needs of the Nation



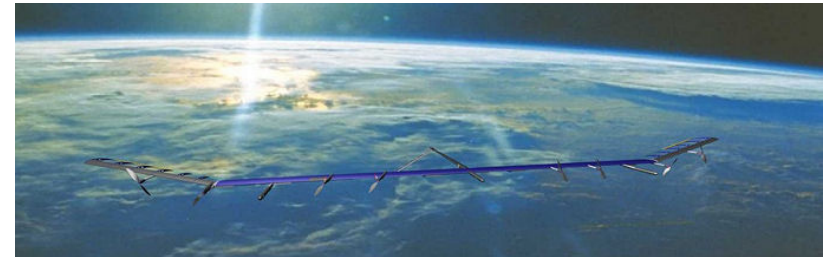


# Opportunities – Air: “We Can Control the Vertical”



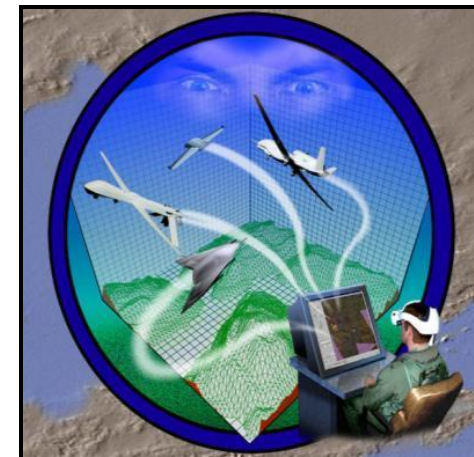
- **C<sup>2</sup>ISR (High-to-Medium Altitudes)**

- Endurance
  - Aerodynamics
  - Propulsion
- Layered Sensing
  - Sensors
  - Processing & Integration



- **ATTACK (Medium Altitudes)**

- Swarming Brains (UAVs)
  - Programming & Processing



- **URBAN & SOLIC (Low Altitudes)**

- Maneuverability
  - Morphing structures, bio-mimetics
- Miniaturization
  - Micro- & Nano-
- Autonomy
  - Sensors
  - Game Theory & Processing





# Opportunities – Space: SSA & ORS



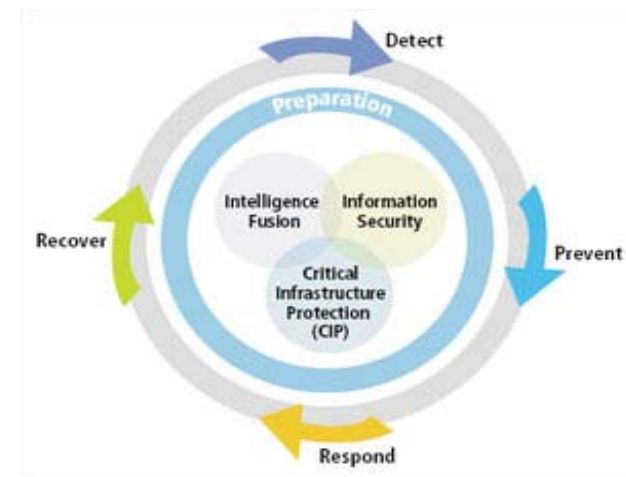
- **Space Situational Awareness**
  - High resolution imaging
  - Electro-optical phenomenology
  - Advanced astrodynamics
  - Modeling and decision aids
- **Operationally Responsive Space**
  - Plug 'n' Play Satellites
  - Small vs Large Satellites
  - Quick Launch
  - Fast On-Orbit Checkout



# Opportunities – **Cyber:** Robust, Resistant, Resilient



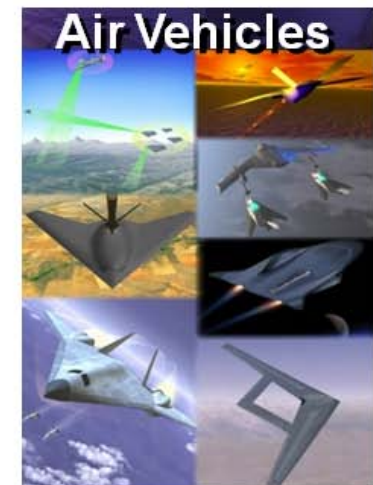
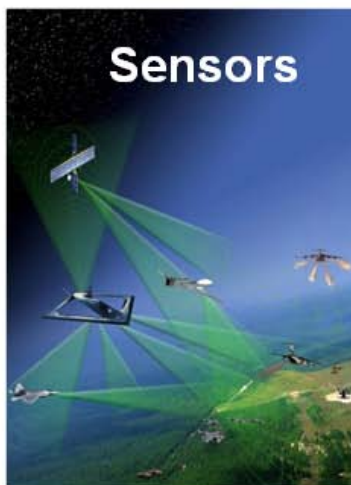
- Must be able to take a series of punches, jabs, feints...and survive!
- “Fight through the Attack!”
  - Endure...mitigate...recover... reconstitute...get up...move forward!
- Move beyond “One Air Force – One Network” to “Defending the Nation”
- Evolve to a polymorphic system of systems that naturally favors:
  - Stability
  - Security
  - Cyber-Sensing
  - Partitionable
  - Rapid Reconstitution
  - Focus on Protecting & Delivering Data





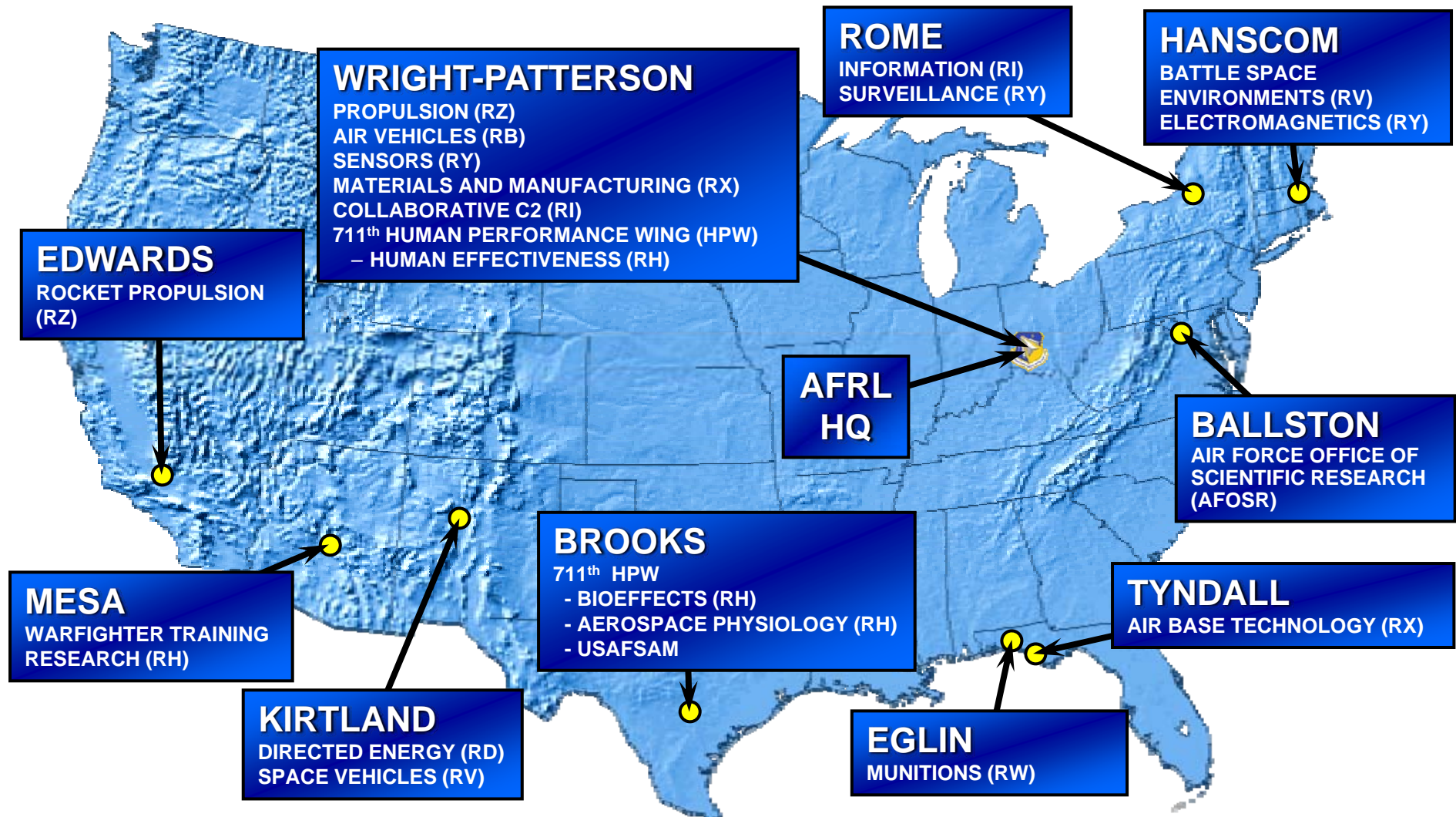


# Ten Technical Directorates





# Major AFRL Facilities



## 40 Sites World-Wide



# Focused Long Term Challenges and Discovery



- FLTC #1** Anticipatory Command, Control & Intelligence (C2I)
- FLTC #2** Unprecedented Proactive Intelligence, Surveillance and Reconnaissance (ISR)
- FLTC #3** Dominant Difficult Surface Target Engagement/Defeat
- FLTC #4** Persistent & Responsive Precision Engagement
- FLTC #5** Assured Operations in High Threat Environments
- FLTC #6** Dominant Offensive Cyber Engagement
- FLTC #7** On-demand Force Projection, Anywhere
- FLTC #8** Affordable Mission Generation & Sustainment
- Discovery** Questions the Air Force doesn't even know to ask





# Rapid Reaction Solution for Brownout



## PhLASH - Photographic Landing Augmentation System for Helicopters



### Problem

- Helicopter landings at arid sites stir up blinding dust clouds (Brown-out)

### Solution

- High resolution image of the landing zone and fly into the image



**9 months from  
Idea to Demo**



### Technologies

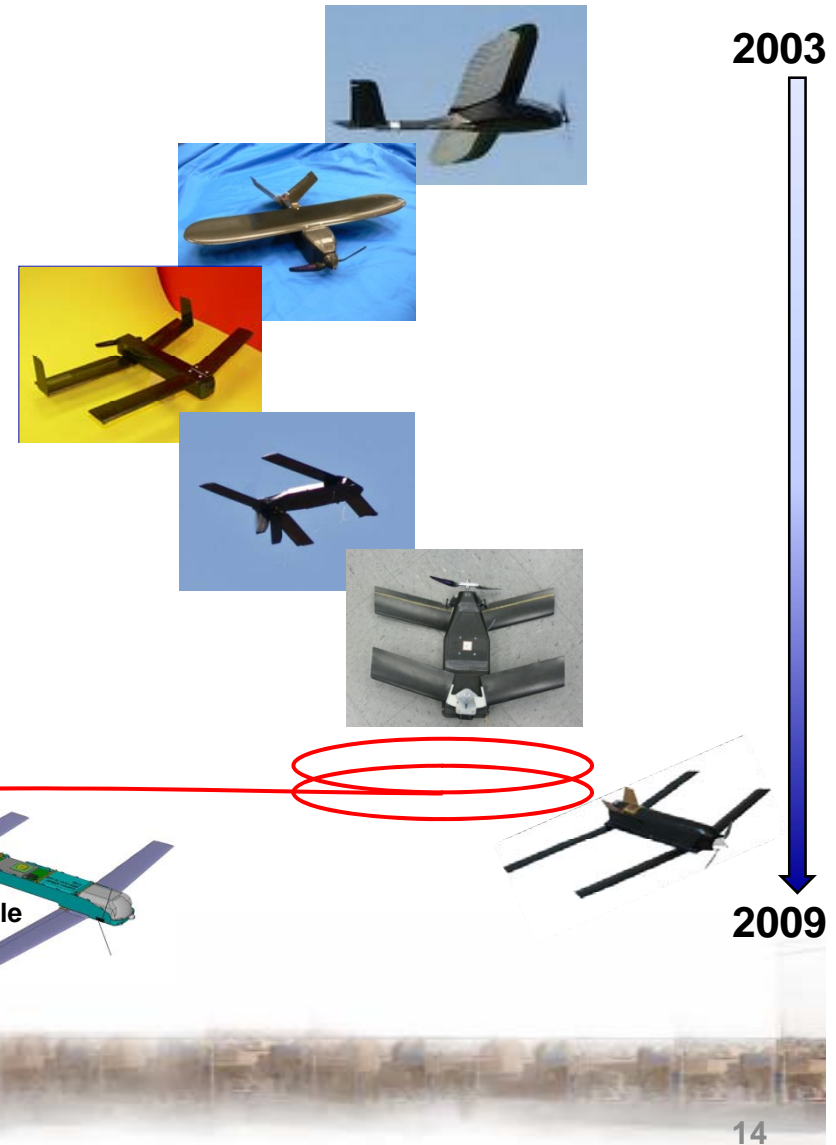
- High Resolution Near-IR flash photography
- Advanced Image processing / reconstruction based on GPS location



# Micro Air Vehicle Development



- Built many mission specific development designs
  - Bomb Damage Information sensing, chem/bio sensing, terminal guidance improvements, weaponization, and general R&D activities for both AFRL and other government agencies
- Optimized Tandem wing design
- Air launch and dismount tube launch
- Pictures show the family of AFRL MAVs from 2003 to present

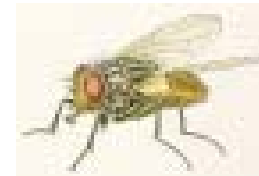
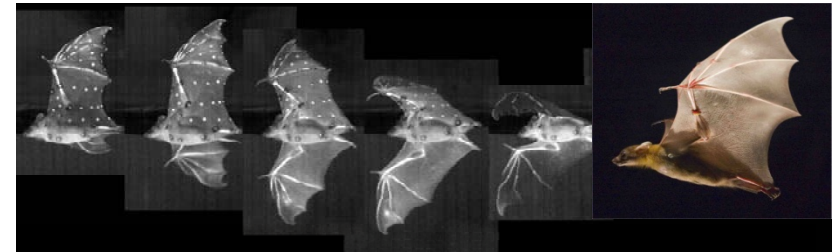




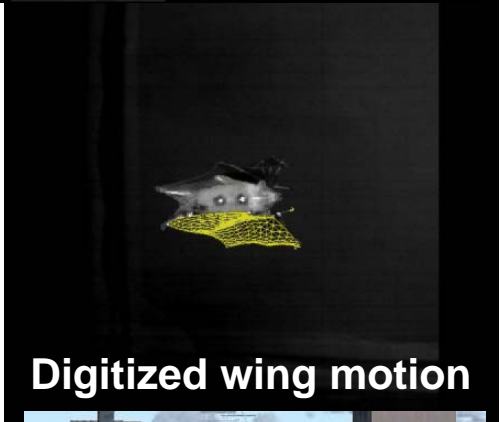
# Bio-Inspired Micro Air Vehicles



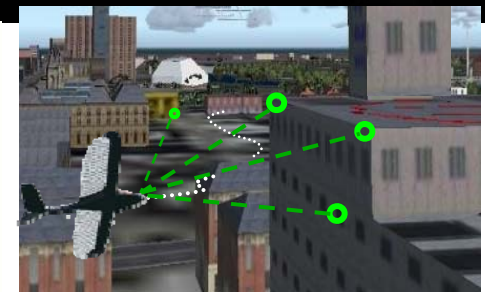
- Characterize aeromechanics and scalability of bat flight
- Bat wing motion has many Degrees of Freedom, unlike insects/birds
- Highly flexible wing structure & membrane
- Arrays of raised hair sensors-actuators that may provide flow sensing & influence flight control
- Active vision control (fly eye) for imaging, tracking and guidance



Play Video



Digitized wing motion



Bio-Inspired: Fly eye & Bat Flight Kinematics

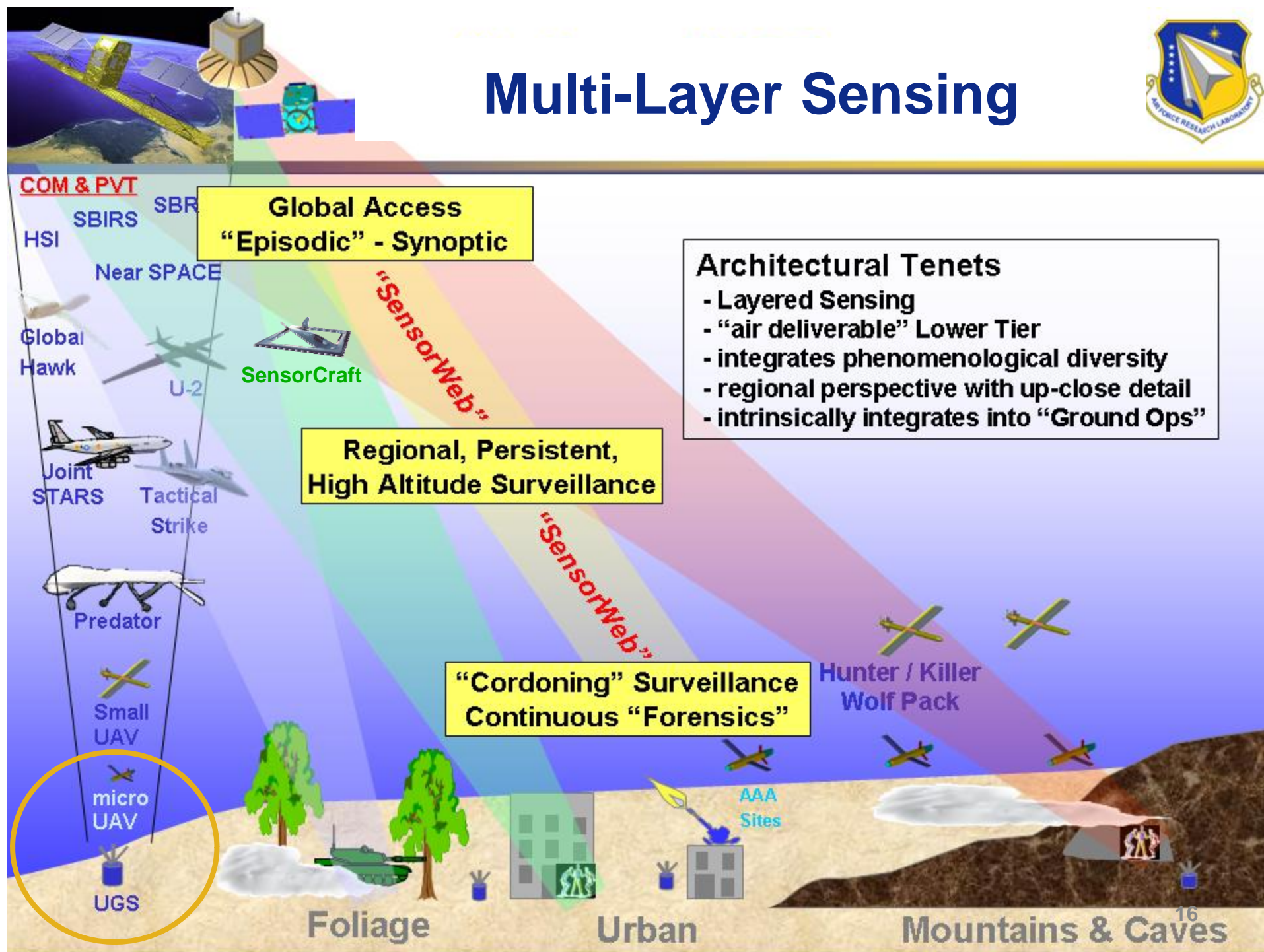
**2015 Goal: Bird-Sized MAV**

**2030 Goal: Insect-Sized MAV**





# Multi-Layer Sensing





# AFRL Staring Sensor Technology



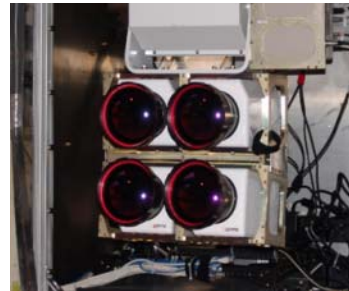
Day (AngelFire)



IRAQ



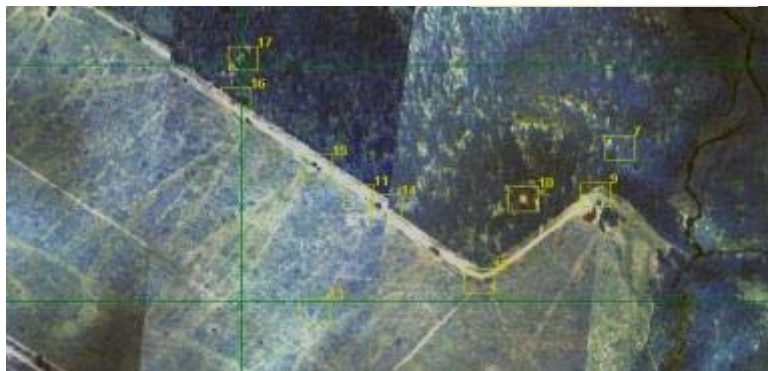
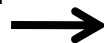
IR (Night Stare)



Area B



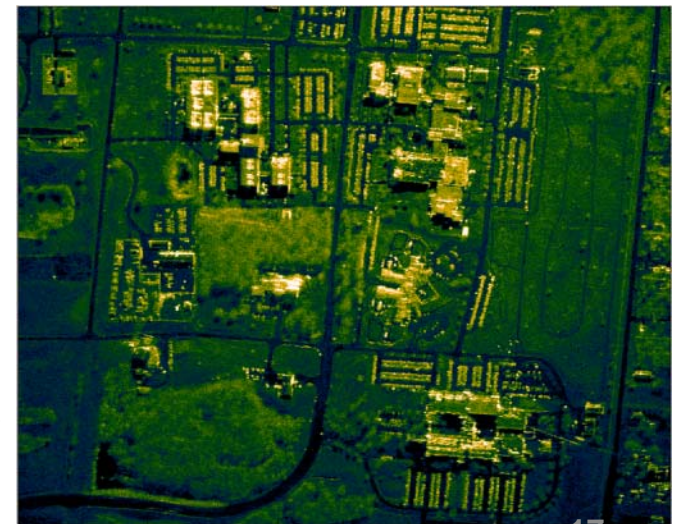
Multispectral  
(SPIRITT) Sensor



Radar  
All Weather

Video SAR  
(Gotcha)

Area B







# Synthetic Aperture LADAR (SAL)

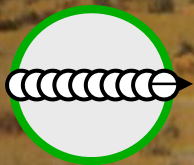


## Synthetic Aperture LADAR for Tactical Imaging (SALTi)

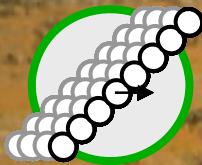
- Demonstrated world's first airborne synthetic aperture LADAR
- ACC Commissioned Advanced Technology Demonstration (ATD)

- Image resolution of current systems limited by size of physical aperture
- Synthetic and sparse aperture methods provide resolution better than allowed by the aperture and the atmosphere

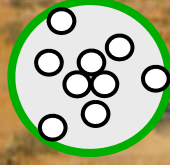
Temporal Synthesis  
(Synthetic Aperture)  
Translation Only



Cross Over (Phased  
Arrays) Translation  
& Separation



Spatial Synthesis  
(Sparse Apertures)  
Separation Only



Azimuth SAR  
Resolution

Cross Track  
Resolution

Single SAL beam ideal  
for high resolution  
imaging

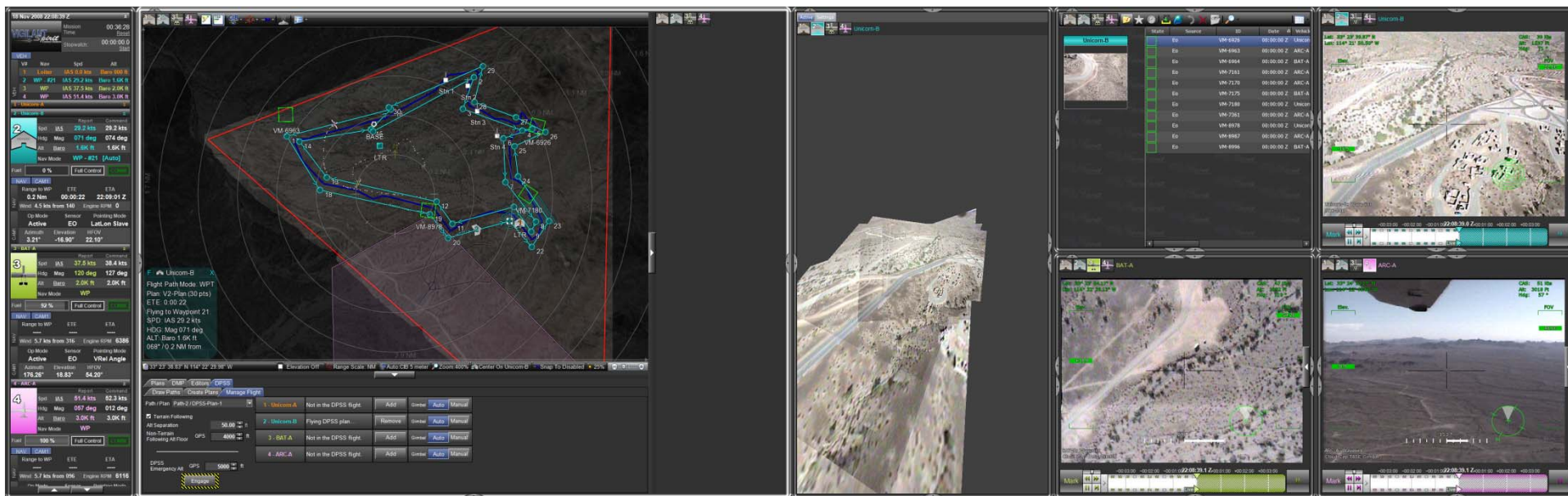
Diffraction Limited  
Resolution



# COUNTER: Cooperative Operations in Urban Terrain



- Automated control system for multiple UASs
  - Allocate Resources
  - Route Vehicles
  - Avoid no-fly zones
  - Respond to alarms
- Data collection interface for ISR
  - Steer sensors
  - Fuse Information



**Yuma Flight Test – Nov 08**  
**(4 Vehicles – 2 Zaggi's, 1 Bat-III, 1 Acturus T-16)**

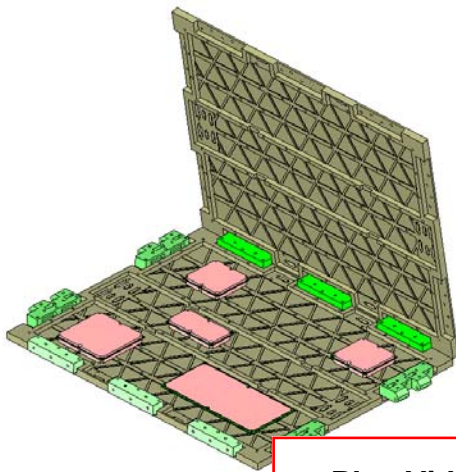




# Operationally Responsive Space



- Apply operational aircraft concepts to space systems
  - Tailored mission capabilities
  - Rapid Build-Up/Turn times
  - Air Tasking Order responsiveness
  - Satellite buses with plug-and-play payloads
  - Sustained high operations tempo

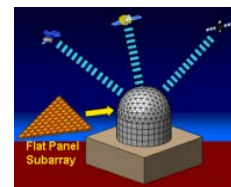


Play Video

Responsive Spacecraft



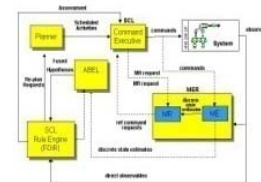
Ground Handling



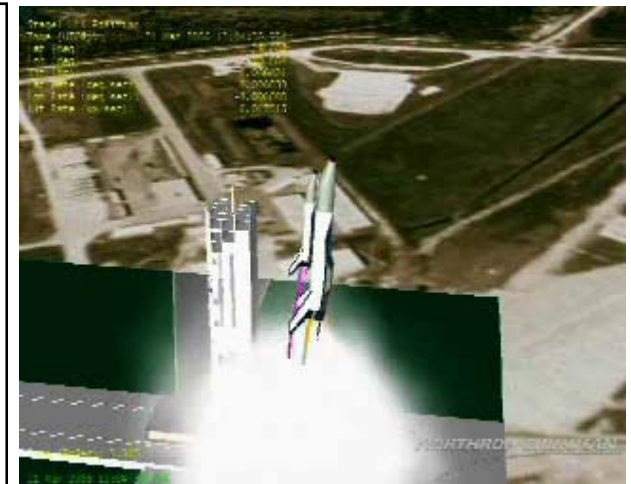
Satellite Control



On-Orbit Checkout



On-Orbit Autonomy

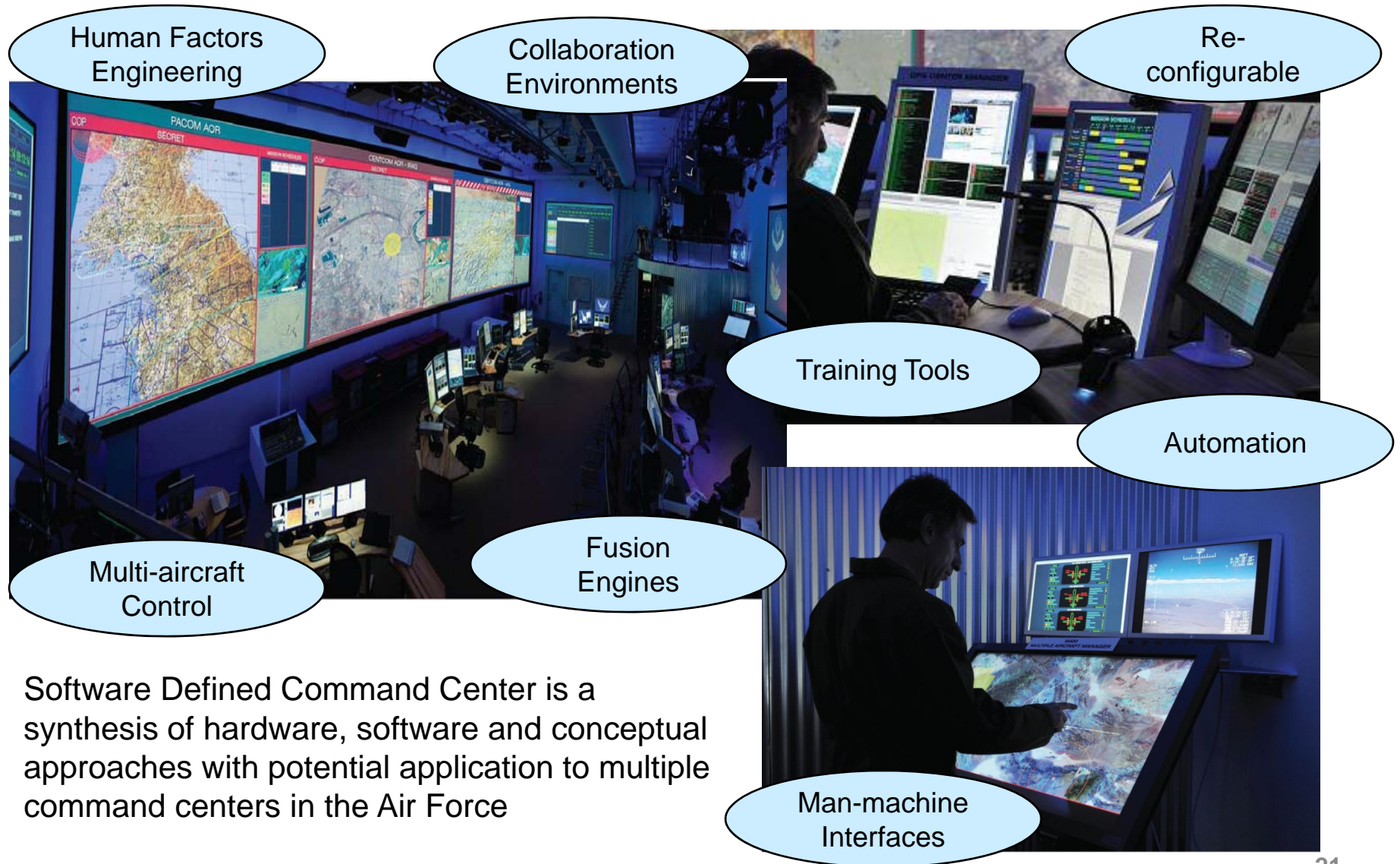


Responsive Launch

## Responsive Operations



# Software Defined UAV Ops Center Mock-up



Software Defined Command Center is a synthesis of hardware, software and conceptual approaches with potential application to multiple command centers in the Air Force



# SensorCraft

## Future High Altitude Long Endurance ISR Platform



| Global Hawk                                   | Next Generation System  |
|---|---|
| 24+ Hours of endurance                        | Highly fuel efficient, 40-50 hours of endurance   |
| Single Band (X) Air to Ground sensing payload | Dual Band (UHF and X), Air to Air <u>and</u> Air to Ground sensing for small and hidden targets |
| Side looking                                  | 360 degree coverage   |
| Raw data to Mission Control Element           | Fused data to user  |
| Conventional antennas, radomes                | Large, embedded structural arrays   |
| Conventional wings, 139 ft                    | Flexible active wings, 200+ ft  |

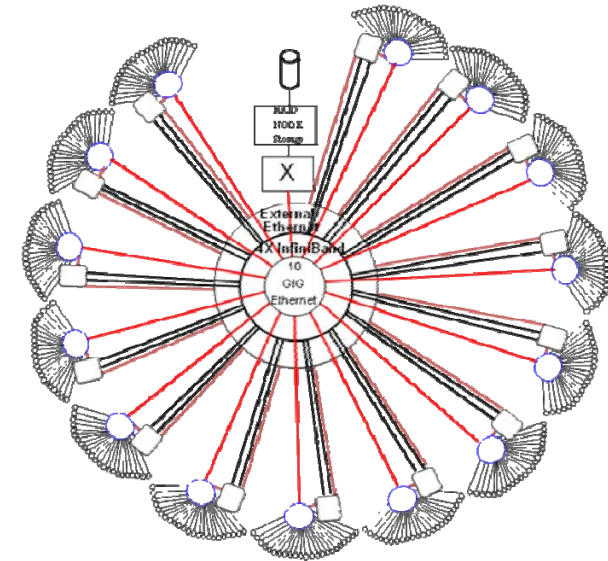




# 53 TFLOPSs Cell Cluster Architecture



- The Cell Cluster has a peak performance of 51.5 Teraflops from 336 PS3s and additional 1.4 TF from the headnodes on its 14 subclusters.
- Cost: \$361K (\$257K from HPCMP)
  - PS3s 37% of cost
- Price Performance: 147 TFLOPS/\$M
- The 24 PS3s in aggregate contain 6 GB of memory and 960 GB of disk. The dual quad-core Xeon headnodes have 32 GB of DRAM and 4 TB of disk each.





## Cell Cluster: Early Access to Commodity Multicore



This project provides the HPCMP community with early access to HPC scale commodity multicore through a 336 node cluster of PS3 gaming consoles (53 TF).

Applications leveraging the >10X price-performance advantage include:

large scale simulations of neuromorphic computing models  
GOTCHA radar video SAR for wide area persistent surveillance

Real-time PCID image enhancement for space situational awareness

*Dr. Richard Linderman, AFRL/RI, Rome, NY*

...but beginning to perceive  
that the handcuffs were not  
for me and that the military  
had so far got...

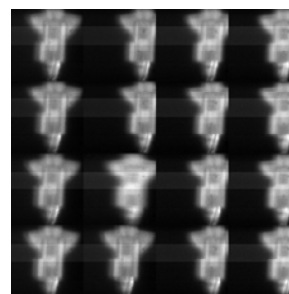
... but beginning to perceive  
that the handcuffs were not  
for me and that the military  
had so far got ...

Neuromorphic example:

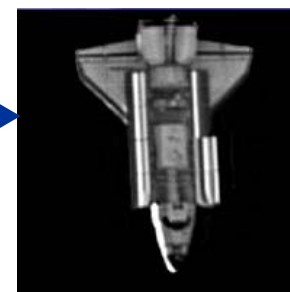
Robust recognition of occluded text



Gotcha SAR



PCID  
Image  
Enhancement

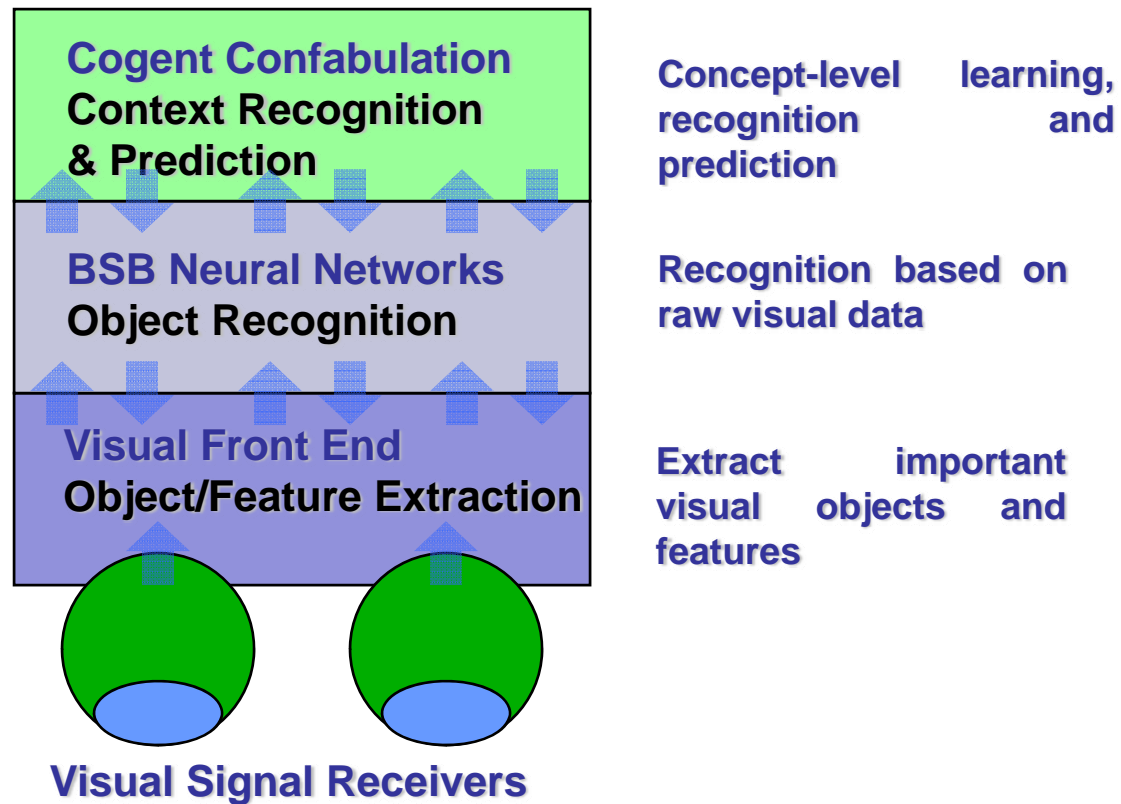


10 March 2009

*Solving the hard problems . . .*



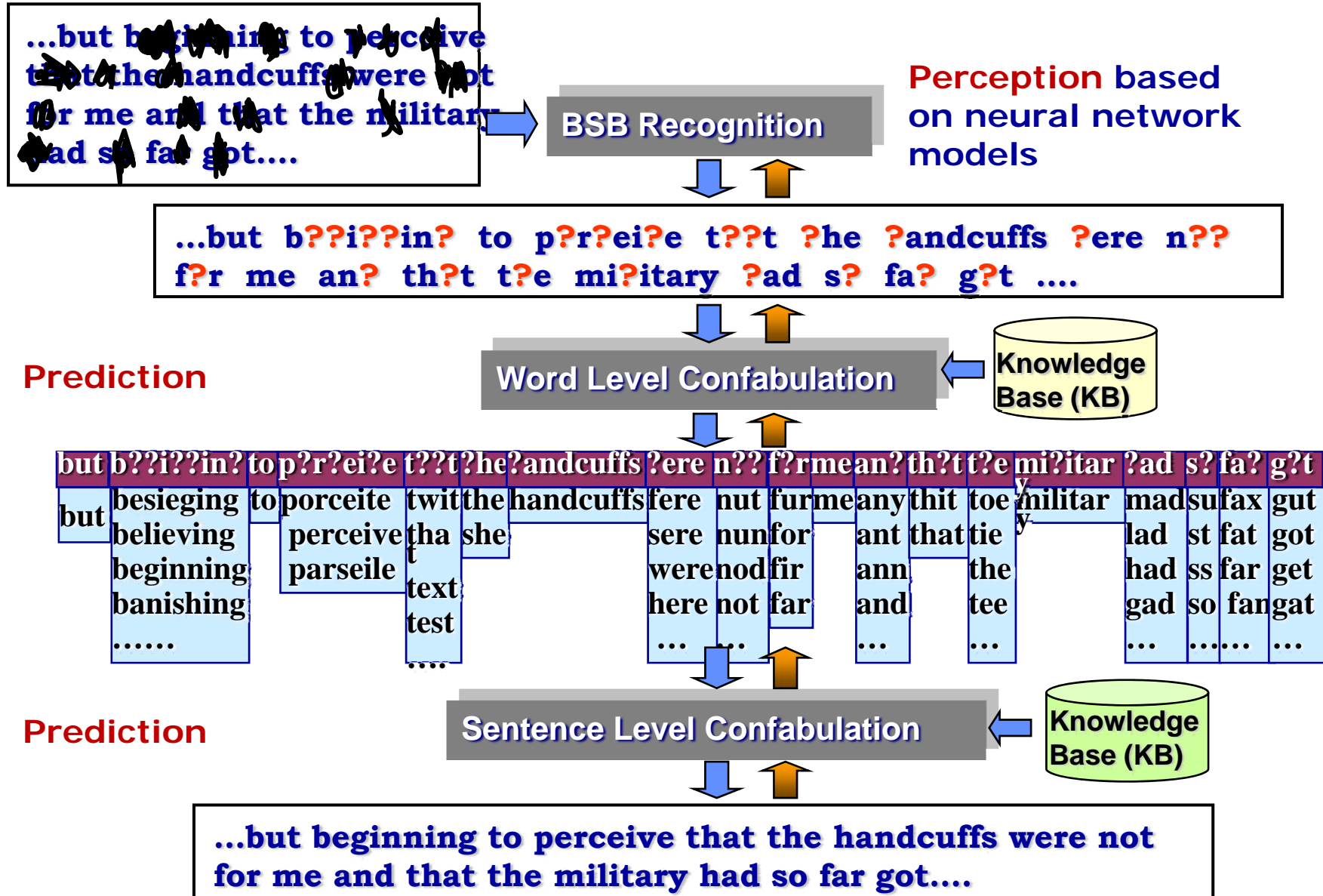
## An Integrated Framework for Visual Cognition







# Hybrid Cognitive Model for Text Recognition

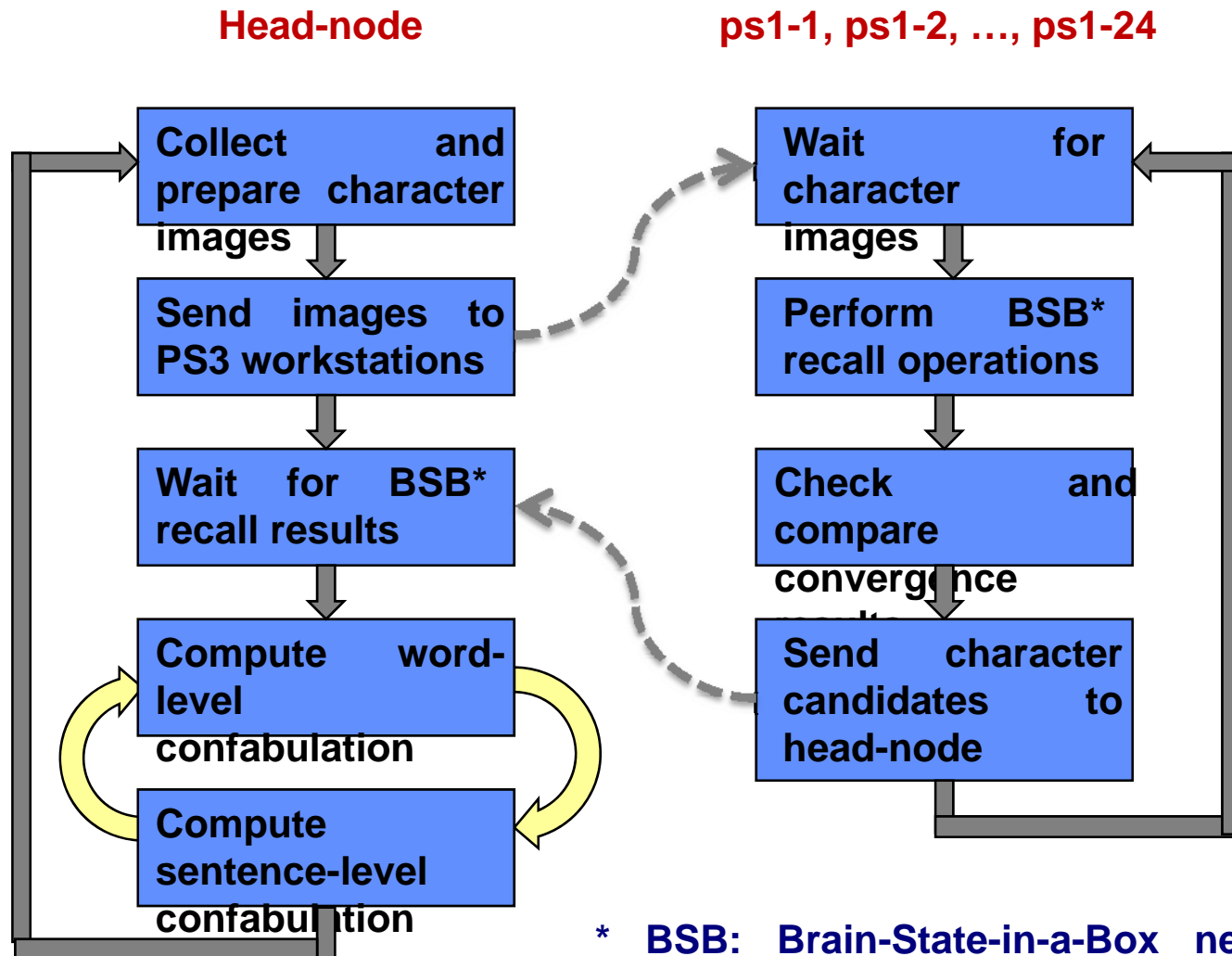




# Text Recognition Workflow on PS3 Cluster



Single PS3 sub-cluster: 1 head-node + 24 Playstation3 (PS3) workstations



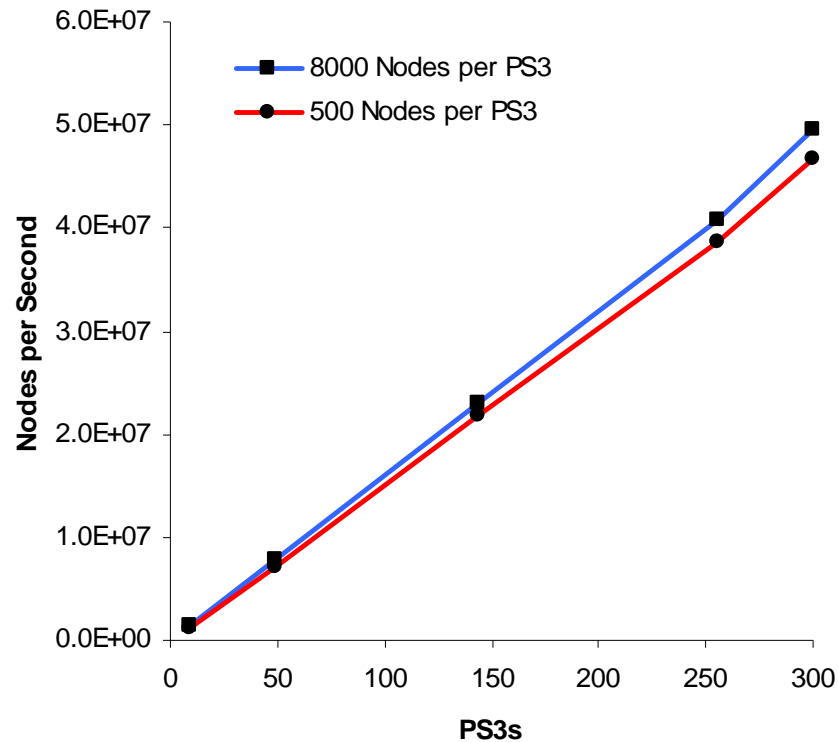
\* BSB: Brain-State-in-a-Box neural network model



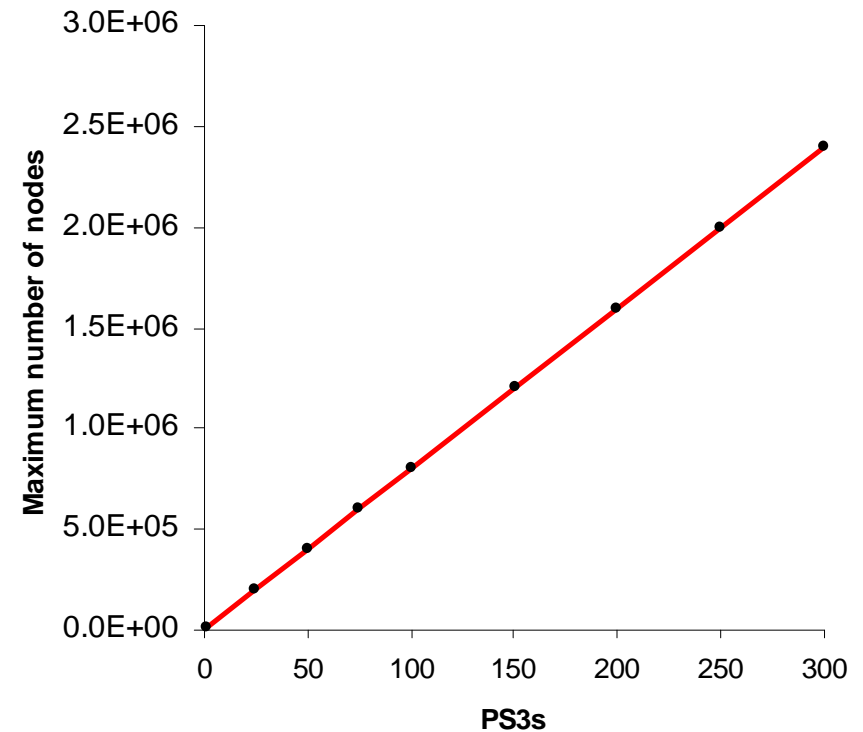
# Scaling the Hierarchical Temporal Memory Model



## Run Time Performance



## Network capability



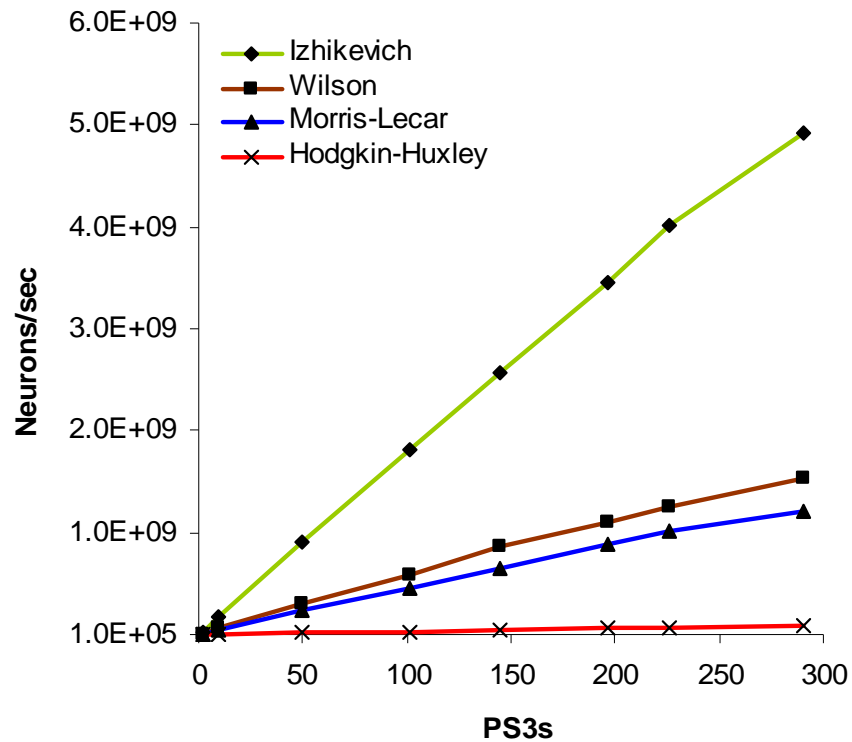




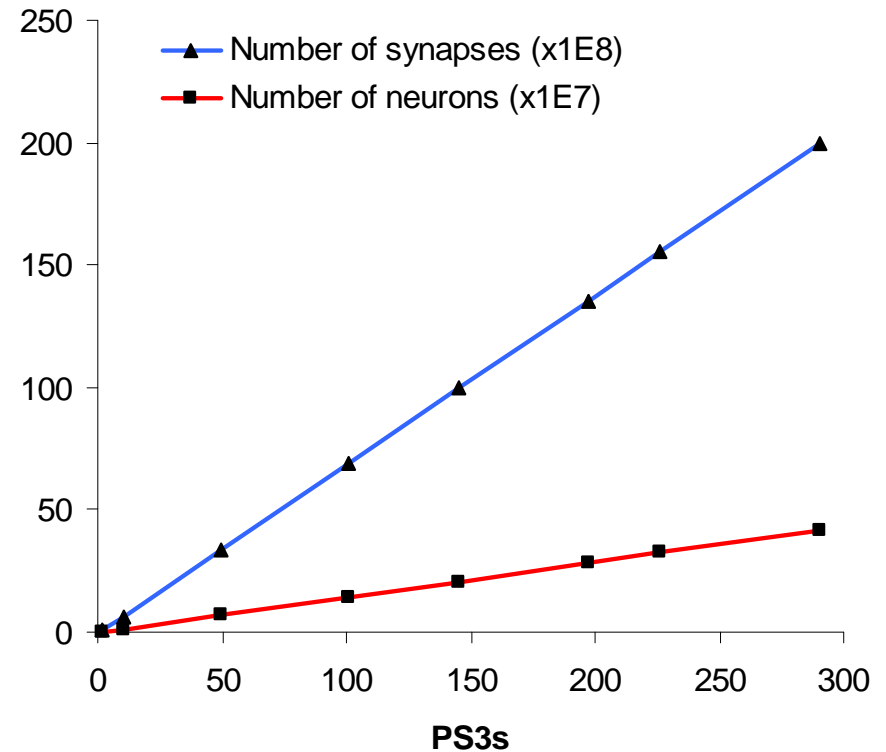
# Scaling Spiking Neural Net Models



## Run Time Performance



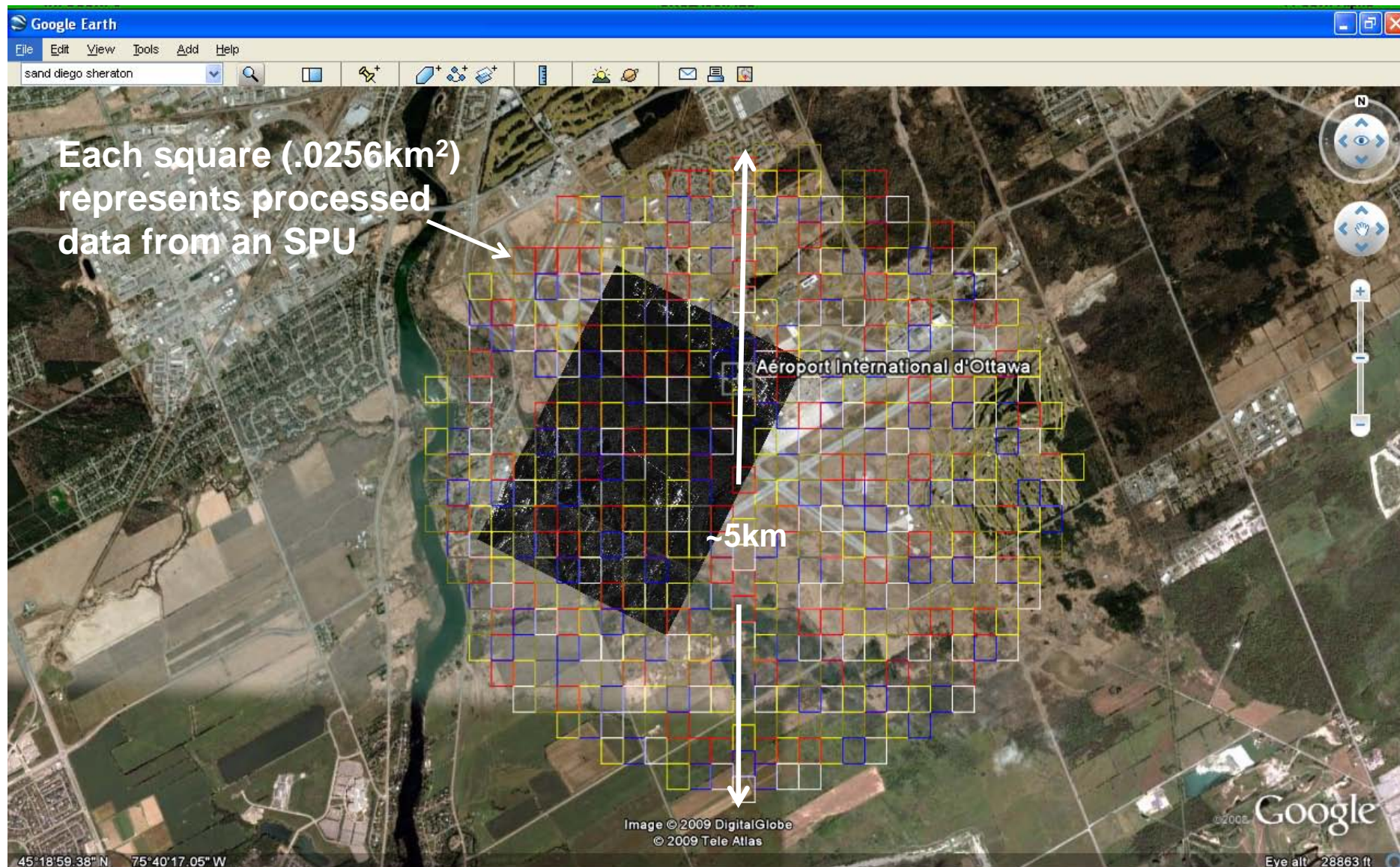
## Network capability\*



\*Note that the number of neurons and synapses that could be implemented are heavily determined by the specific network structure developed. More biologically accurate models are currently being studied and are likely to yield different numbers.



# 96 PS3's (576 SPU cores) processing 5km Gotcha SAR

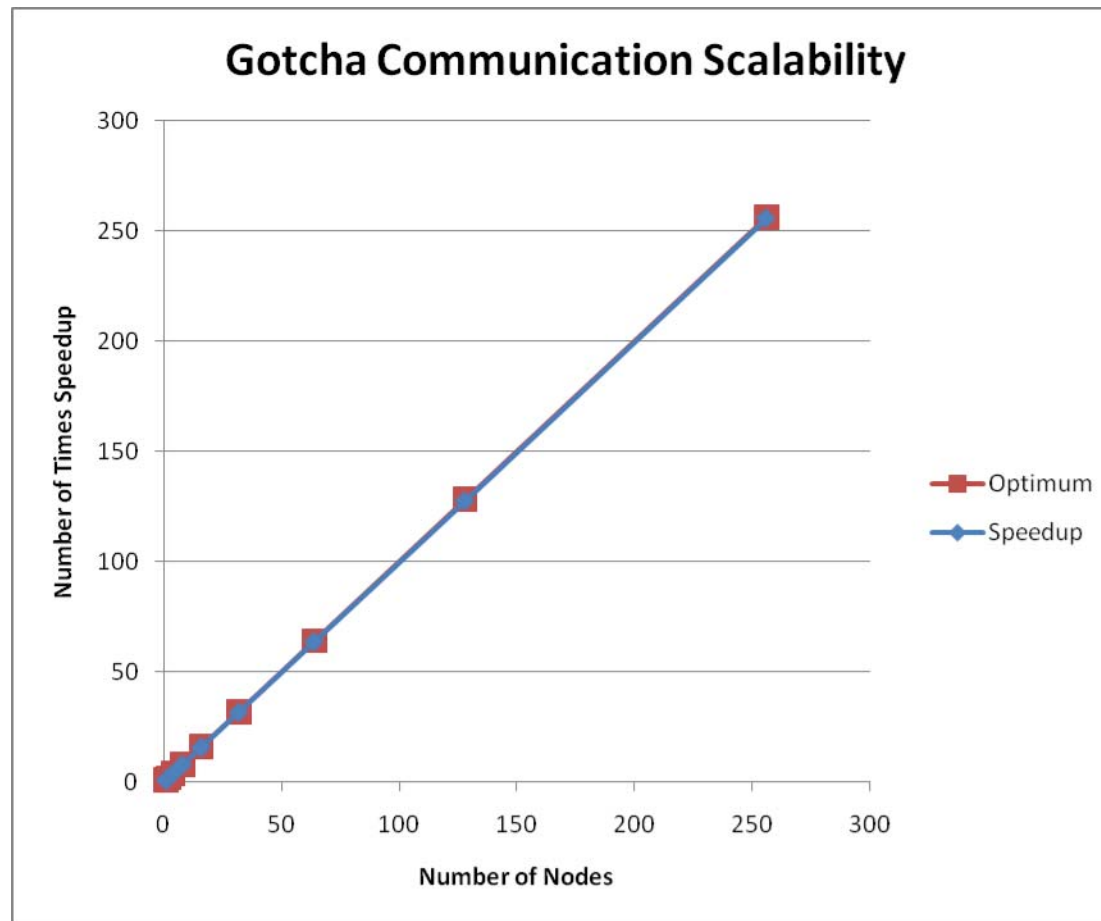




# Results: Gotcha VideoSAR Scalability



- At 256 PS3s, each send 6 MB/sec and receives 8.4 MB/sec while headnodes each receive 200 MB/sec and send 140 MB/sec







# Great News for HPEC!



OFFICE OF THE DIRECTOR  
DEFENSE RESEARCH AND ENGINEERING  
3040 DEFENSE PENTAGON  
WASHINGTON, D.C. 20301-3040

2 June 2009

MEMORANDUM FOR DEPUTY ASSISTANT SECRETARY OF THE ARMY (RESEARCH AND TECHNOLOGY)  
CHIEF OF NAVAL RESEARCH  
DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE (SCIENCE, TECHNOLOGY AND ENGINEERING)  
DIRECTOR, PROGRAM ANALYSIS AND EVALUATION  
DIRECTOR, TEST AND EVALUATION AND TECHNOLOGY REQUIREMENTS, DEPARTMENT OF THE NAVY  
DIRECTOR, MISSILE DEFENSE AGENCY  
DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY  
DIRECTOR, DEFENSE THREAT REDUCTION AGENCY  
DIRECTOR, TEST AND EVALUATION MANAGEMENT AGENCY, DEPARTMENT OF THE ARMY  
DIRECTOR, TEST AND EVALUATION DIRECTORATE, DEPARTMENT OF THE AIR FORCE

SUBJECT: FY 2010 DoD High Performance Computing Modernization Program Dedicated HPC Project Investment Awards

Reference: Office of the Director, Defense Research and Engineering Memorandum, Subject: *Call for DoD FY 2010 Dedicated High Performance Computing Project Investment (DHPI) Proposals*, December 2008


Dedicated HPC Project Investments (DHPIs) are modest-sized HPC systems that are awarded to technically sound, mission critical projects which cannot be performed at DoD Supercomputing Resource Centers (DSRCs) due to classification level, special operational requirements (e.g., real-time turnaround), and/or use of emerging technologies. DHPIs are a vital part of the DoD HPC Modernization Program's mission to address the most pressing HPC needs of the DoD S&T and T&E communities.

All proposals were subjected to rigorous independent review by the DHPI Technical Evaluation Panel (which includes HPC subject matter experts from Government, industry, and academia), the Service/Agency Principals, and the DUSD(S&T) Directors. I would like to thank the Service/Agency Principals for their careful review and refinement of this year's DHPI proposals. As a result, the process was more competitive and aligned with DoD priorities.

It is my pleasure to announce that the following DHPIs have been selected for award for FY 2010:

| DHPI  | Organization  | Project Leader    |
|---|---|-------------------|
| Maui Space Surveillance System Advanced Image Reconstruction                  | Air Force Research Laboratory, Directed Energy Directorate (RD) | Maj. David Strong |
| 500 Tflop/s Cluster for Real-Time Neuromorphic Computing and Gotcha Video SAR | Air Force Research Laboratory, Information Directorate (RITB)   | Mr. Mark Barnell  |
| Persistent Surveillance Supercomputing  | MIT Lincoln Laboratory  | Dr. Jeremy Kepner |

I ask your assistance and continued involvement to ensure that the HPC assets being acquired under these awards are best employed to meet the specific needs of the selected DHPI projects. Please join me in congratulating the awardees.

  
André van Tilborg  
Deputy Under Secretary of Defense  
(Science and Technology)

cc:  
PD, DDR&E  
DoD High Performance Computing Advisory Panel  
Project Leaders





# Top 500 Supercomputers June 2009

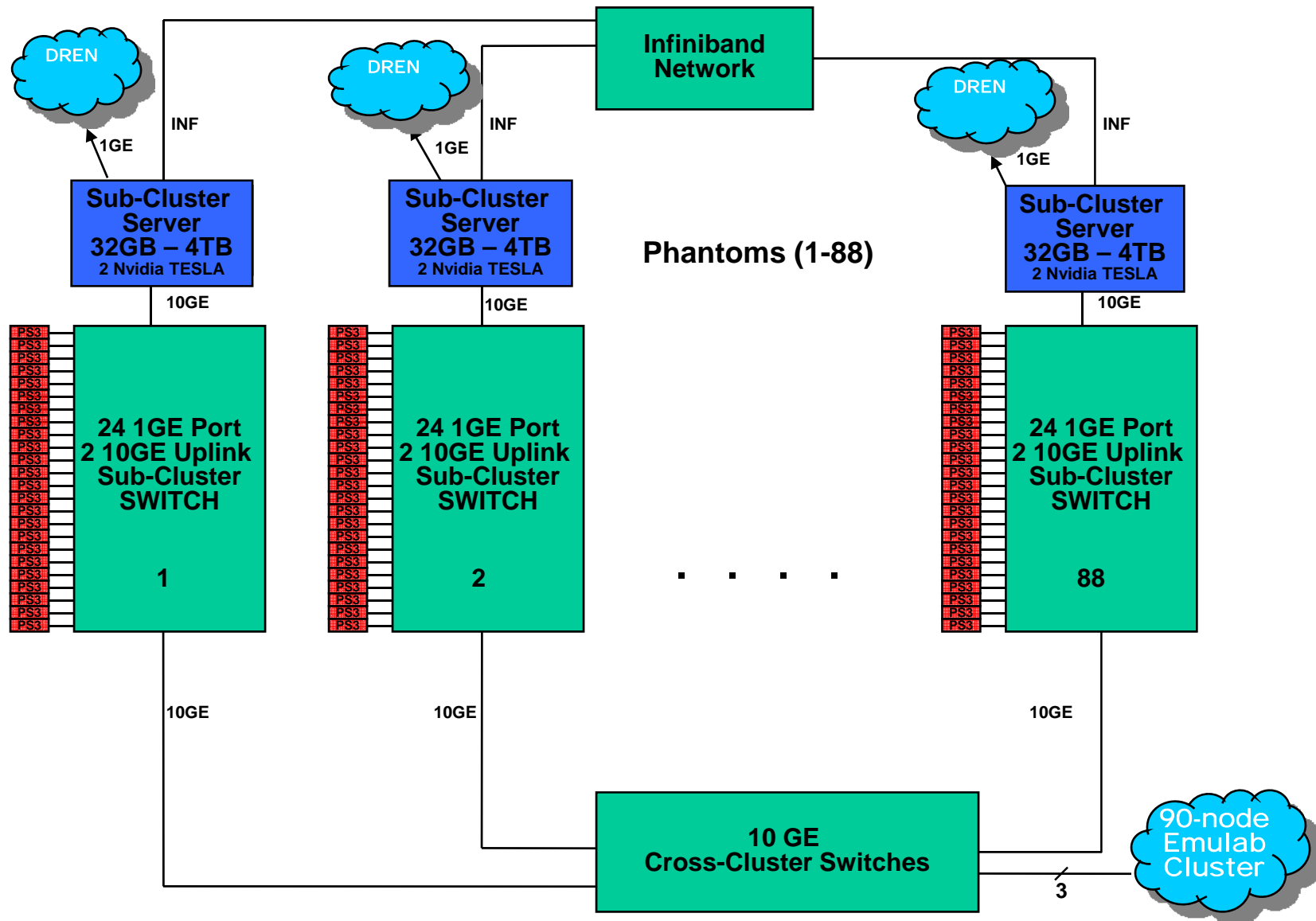


| Rank | Site   | Computer/Year Vendor  | Cores  | R <sub>max</sub> | R <sub>peak</sub> | Power   |
|------|--|---|--------|------------------|-------------------|---------|
| 1    | <a href="#">DOE/NNSA/LANL</a><br>United States                 | <a href="#">Roadrunner - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband</a> / 2008<br>IBM | 129600 | 1105.00          | 1456.70           | 2483.47 |
| 2    | <a href="#">Oak Ridge National Laboratory</a><br>United States | <a href="#">Jaguar - Cray XT5 QC 2.3 GHz</a> / 2008<br>Cray Inc.  | 150152 | 1059.00          | 1381.40           | 6950.60 |
| 3    | <a href="#">Forschungszentrum Juelich (FZJ)</a><br>Germany     | <a href="#">JUGENE - Blue Gene/P Solution</a> / 2009<br>IBM   | 294912 | 825.50           | 1002.70           | 2268.00 |
| 4    | <a href="#">NASA/Ames Research Center/NAS</a><br>United States | <a href="#">Pleiades - SGI Altix ICE 8200EX, Xeon QC 3.0/2.66 GHz</a> / 2008<br>SGI   | 51200  | 487.01           | 608.83            | 2090.00 |
| 5    | <a href="#">DOE/NNSA/LLNL</a><br>United States                 | <a href="#">BlueGene/L - eServer Blue Gene Solution</a> / 2007<br>IBM   | 212992 | 478.20           | 596.38            | 2329.60 |

By comparison, the world's largest HPC (Roadrunner at Los Alamos) is 2800 teraflops (single precision) and runs in batch mode.

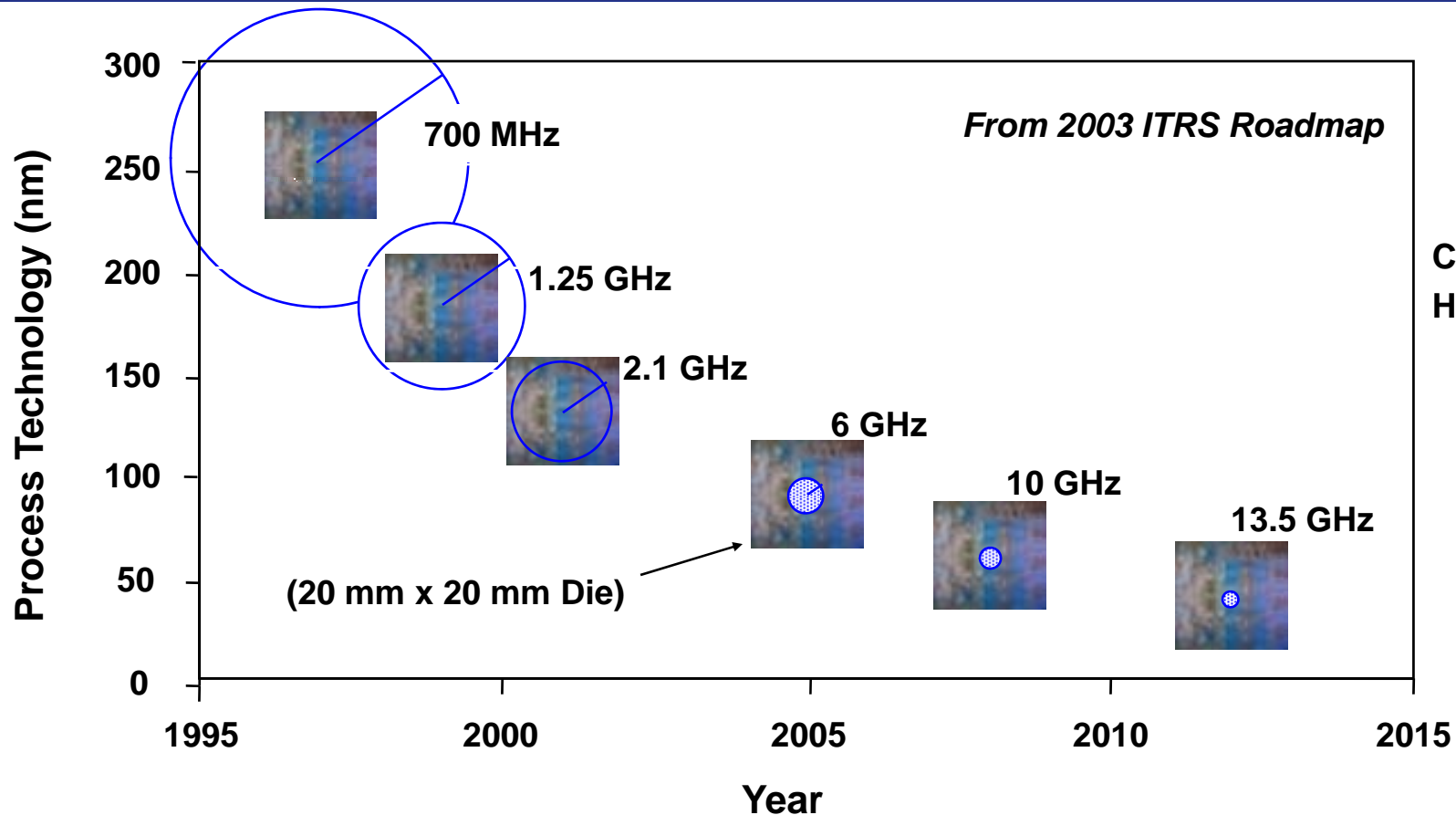


# 500 TFLOPS Interactive Cluster (300 Cell, 200 GPGPU)





# Range of Wire in One Clock Cycle\*



Craig Keast,  
HPEC-06

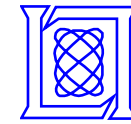
- 3D Integration increases accessible active devices

\*After S. Amarasinghe, MIT Laboratory for Computer Science and Artificial Intelligence



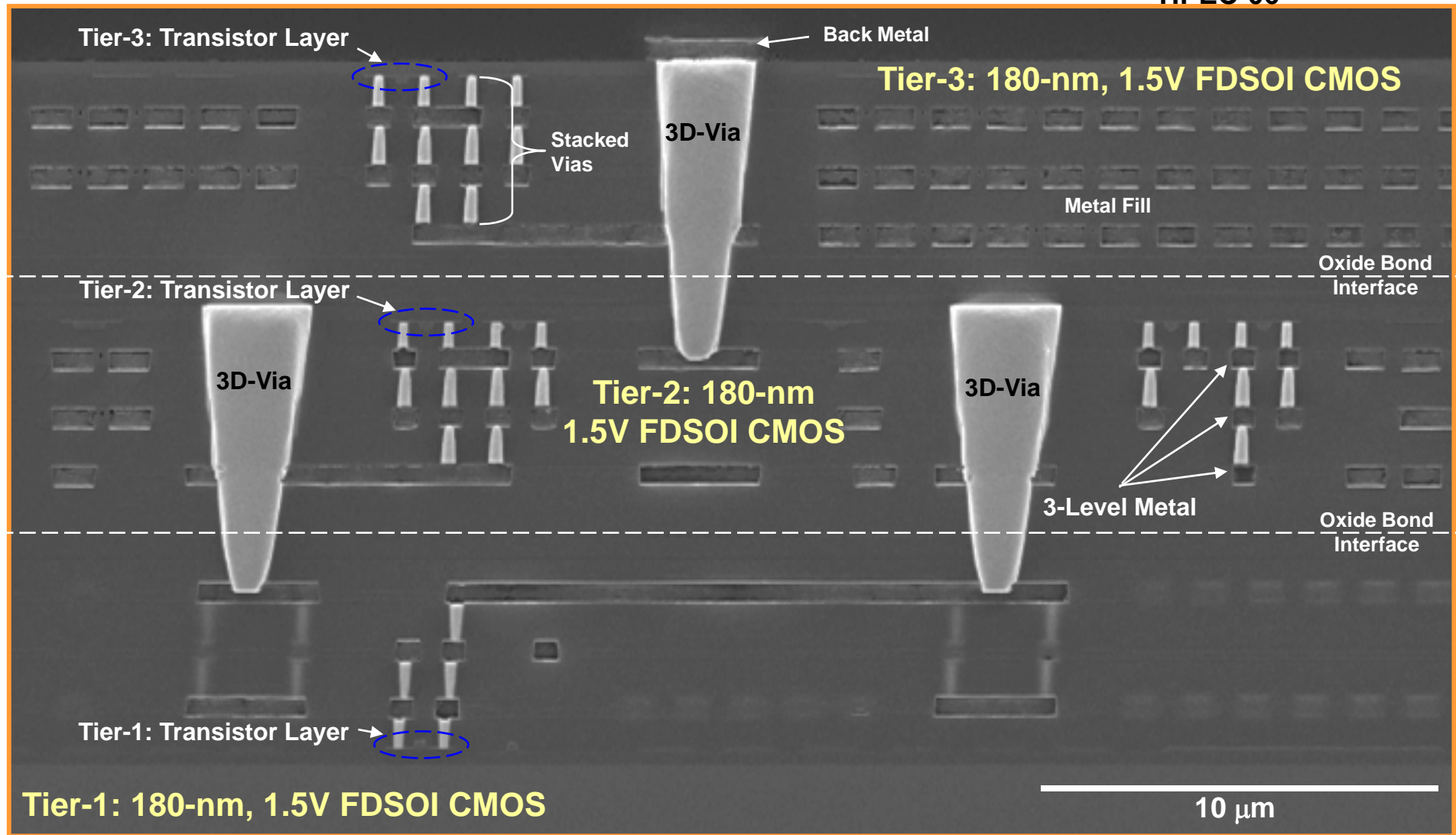
# Cross-Section of 3-Tier 3D-integrated Circuit

## 3 FDSOI CMOS Transistor Layers, 10-levels of Metal



Craig Keast,

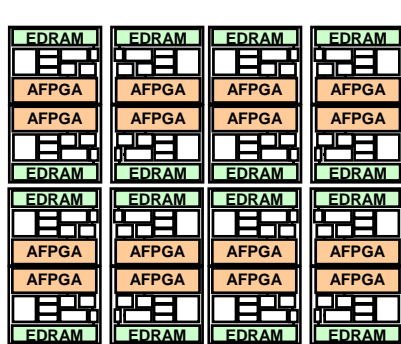
HPEC-06







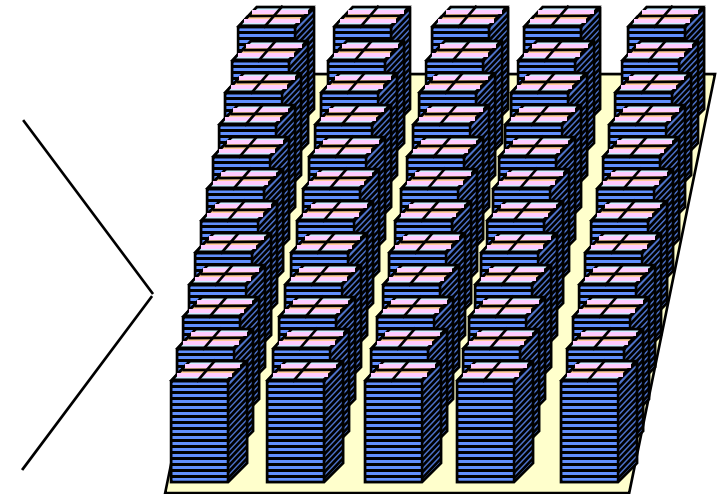
# Pushing 3D Multicore Architecture



16 cores / chip



50 chips / stack



10 x 10 stacks / board

At 100 GFLOPS/Watt (45 nm):

0.32 watts

16 cores

32 GFLOPS Single Precision  
16 GFLOPS Double Precision

32 watts

800 cores

1.6 TFLOPS

1.6 kwatts

80K cores

160 TFLOPS



# Some Daunting HPEC Challenges



**Information System Complexity**

**Physical System Complexity**

**Autonomous Systems**

**Fusion, Automatic Target Recognition**

**Situational Awareness**

**Keep redoubling the performance/dollar!**

**But also make the entire HW/SW system timely and affordable**

The logo for the Air Force Research Laboratory (AFRL) is displayed in a large, bold, sans-serif font. The letters 'A', 'F', and 'R' are white with a grey outline, while the 'L' is solid white. To the right of the text is a small, stylized globe graphic composed of a grid of dots.

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